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THE PERFORMANCE ENHANCEMENT OF AXIAL FLOW TURBINE USING NUMERICAL TECHNIQUE

REVATHI RAMAKRISHNAN[1] & SRINIVAS. G[2*]

[1]*Student, Department of Instrumentation and Control Engineering, Manipal Institute of Technology, MAHE, Manipal, Karnataka, India*

[2]*Assistant Professor (Sr. Scale), Department of Aeronautical and Automobile Engineering, Manipal Institute of Technology, MAHE, Manipal, Karnataka, India*

ABSTRACT

This paper aims to study the performance enhancement of subsonic axial flow turbine using numerical technique. R123 Organic Rankine Cycle (ORC) with high density is considered as the working fluid. A single stage axial flow turbine consisting of stator and rotor is used to carry out the analysis. The numerical analysis is carried out using ANSYS R18.1 version. The parameters considered to design the turbine geometry are tip diameter, hub diameter, blade height, half wedge angle of leading and trailing edge and number of blades of the stator and rotor. The design and study of axial flow turbine is mainly focused for engineers and technical researchers working in the field of ORC and engine design. Grid independence test performed with different mesh size to keep the computational economy intact. The experimental results are later compared with the theoretical calculation for verification.

***KEYWORDS:** Axial Flow Turbine, Organic Rankine Cycle, Subsonic & Performance*

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Original Article

INTRODUCTION

The importance of renewable energy is increasing in the present scenario due to the depletion of fossil fuels. Hence, the research of Organic Rankine Cycle (ORC) came into present scenario. The working fluid flows parallel to the shaft in an axial flow turbine. These type of turbines are used mainly in the application of compressible fluids. The basic function of axial flow turbine is to convert fluid flow into rotational mechanical energy. Axial flow turbine comprises of stator and rotor. The stator and rotor together comprises of a single stage axial flow turbine. The set of stator blades accelerates the swirl to the working fluid while the rotor blade decelerates the flow. Because of this high pressure drop per stage, turbines are capable of operating at the favourable pressure gradient. Therefore, several stages of an axial compressor can be driven with a single stage axial turbine. Axial flow turbines are preferred because of its capability to handle large mass flow rate, efficiency and ease of designing of aerodynamically. Organic Rankin Cycle (ORC) technology are preferred as working fluid because of its efficiency to convert low grade heat to convenient thermal or mechanical power. In this paper numerical analysis on R123 working fluid (Thermodynamic model of ORC) is considered. Schematic diagram of axial flow turbine in turboprop is shown in figure 1.

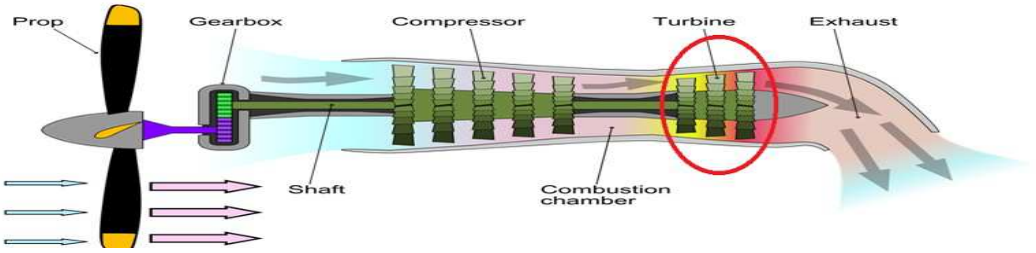

Figure 1: Schematic Representation of Turboprop [14]

LITERATURE REVIEW

Increasing the efficiency of the turbine plays a significant part in the design of an engine. Reynolds number less than 1.0*10^5 affects the turbine blade and not the performance [1]. Increasing the overall efficiency and reducing the loses in the turbine requires high level of research. Laminating the turbine with photo etched laminates improved the durability and mechanical integrity of the blade when compared with the unlamented turbine blades [2]. Reduction of radial and pitch wise smoothening so as to enhance the performance of axial flow turbine was studied in paper[3]. The performance was increased by converting the unsteady state to a steady state using a code developed by Denton. Increasing the turbine inlet temperature increases the efficiency and makes the flow similar to the design condition, depending on the favourable operation [4]. Lifetime of a blade can be improved by lowering the shroud design[6]. Blade count plays an important role in increasing the mass flow rate, when compared to the blade height[7]. However, the power expansion of the turbine can be increased by either increasing the blade angle or reducing blade height and radius[9]. Friction loss incorporated in the turbine is due to hub, blade passage and stationary case[13]. The thermodynamic properties of R123 working fluid showed maximum energy efficiency when compared with other working fluids like R134a, R141a AND R152a[10,13]. Multi Objective Genetic Algorithm(MOGA) technique is adopted to optimize the blade design and reduce total loss[11,13]. The use of fence in secondary wall treatment has a promising use in the secondary flow loss treatment when compared with suction, blowing and air injection[12]. Software's like GT TURO3D(ttsGeorgia Tech Turbo machinery 3D), ANSYS CFX, NUMECA, MATLAB and ICEM CFD was used to model the axial flow turbine[5,6,8].

METHODOLOGY

The numerical analysis of axial flow turbine involves modelling, meshing and analysis of axial flow turbine.

Modelling the Turbine Blade

Geometry and dimensioning of both the stator and rotor blade has been designed separately in ANSYS 18.1 version Bladegen. Modelling of rotor blade in Bladegen is shown in figure 2 and the preliminary design for R123 working fluid [30] is tabulated in Table1:

Table 1: Preliminary Design Data of Axial Flow Turbine Blades [30]

Parameters	Unit	Working Fluid (R123)
Tip diameter	mm	86
Hub diameter	mm	54
Blade Height	mm	16
Stator		
Beta angle of leading edge	deg	-10

Table 1: Contd.,

Beta angle of trailing edge	deg	61
Stagger angle	deg	35
Parameters	**Unit**	**Working Fluid (R123)**
Number of blades		19
Rotor		
Beta angle of leading edge	deg	-17
Beta angle of trailing edge	deg	68
Stagger angle	deg	30
Number of blades		20

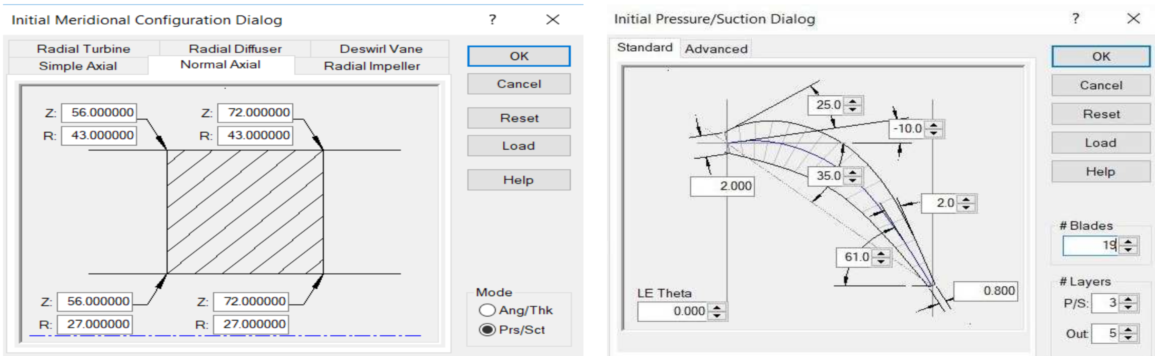

Figure 2: Modeling of a Rotor Blade in Bladegen

Meshing the Turbine Blade

ANSYS R 18.1 TurboGrid is the meshing tool used for generating high quality hexahedral meshes needed for the axial turbine blade passages. Generally, more the number of elements more the accuracy of the results, but, however processing time will also be increased. Grid independence for mesh size 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.5 and 3 were done. In this analysis, mesh size data of 1.25 is considered because of its least error obtained when correlating with theoretical calculation. Hub, tip, and blade surface are refined with computational mesh as shown in figure 3. H mesh type grid with expansion ratio of 1.2 was applied in the three dimensional computational fluid dynamics analysis.

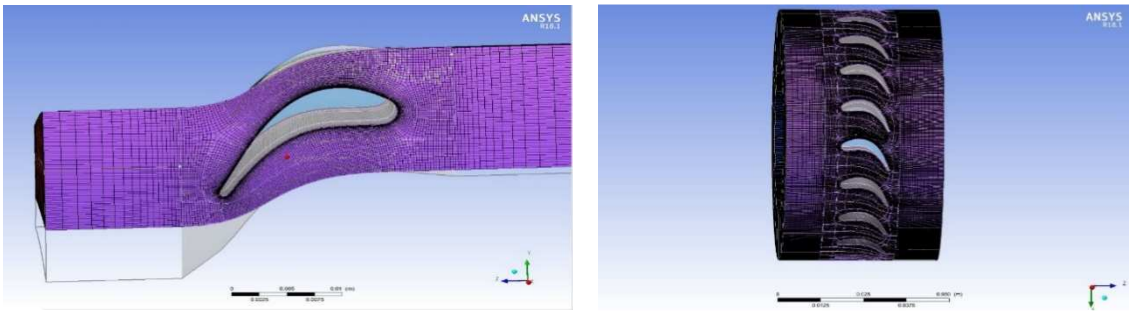

Figure 3: 2D and 3D View of Rotor Blade After Meshing in TurboGrid

Analysis of Axial Flow Turbine

Analysis of axial flow turbine is performed using the feature ANSYS CFX, where CFX stands for Computer Forensic Examiner. This software is used for getting wide range of solutions like aerodynamics, combustion, flow reaction etc. Analysis is performed in CFX due to its high graphic results providing the details of fluid flow heat, heat transfer and other parameter evolved with time, thereby delivering reliable and accurate solutions quickly across multi-physics

application. ANSYS CFX is done in three steps:

- **CFX Setup**: The function of CFX Setup is to hold the data for the instance of CFX-Pre. The data considered for this analysis is tabulated in table 2 and table 3.

Table 2: CFX Pre-Setup

Fluid	Air Ideal Gas
Model Data	
Reference Pressure	0 Pa
Heat Transfer	Total Energy
Turbulence	Shear Stress Transport
Inflow/Outflow Boundary Templates	P-Total Inlet P-Static Outlet
Inflow P-Total	250000Pa
Inflow T-Total	370K
Flow Direction	Normal to Boundary
Outflow P-static	101325 bar
Interface(Default)	Stage (Mixing plane)

Two domain interfaces are considered. Rotor (R1) Domain is rotating while the Stator(S1) Domain is stationary.

Table 3: CFX Setup- Solver Control

Convergence Control	
Min. Iterations	1
Max. Iterations	10000
Convergence Criteria	Total Energy
Residual Type	Shear Stress Transport
Residual Target	P-Total Inlet P-Static Outlet
Equation Class	250000Pa

CFX Solver Manager

This function of CFX Solver Manager is to define the run of the previously saved Solver Input file. The analysis is carried out using Parallel settings. After initializing the run option, the workspace gives information about the plot residuals, imbalances, convergence of solver as shown in figure 4.

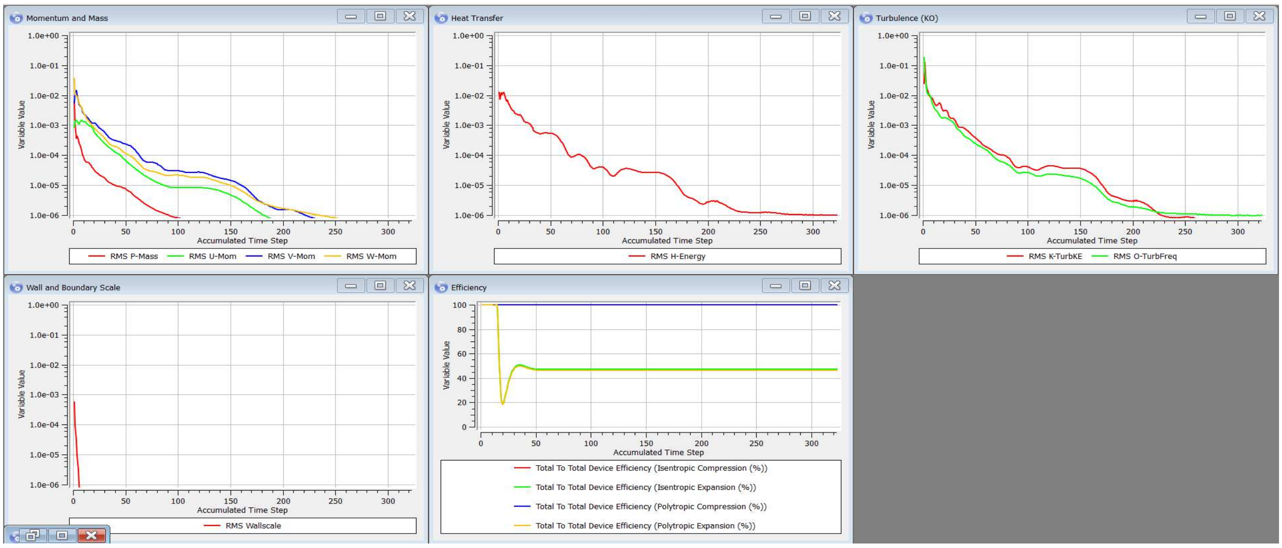

Figure 4: Graphs Obtained in CFX Solver While Running the Solution

RESULT

Result files will be generated after applying the boundary conditions and running the solver parameters. The file generated after this operation are called CFD Post.

- **Pressure:** In figure 5, pressure decreases as it moves from stator to rotor because of the acceleration and deceleration of the respective blades. The maximum and minimum pressure obtained at the inlet and outlet are 271149 Pa and 43964.6 Pa respectively.
- **Temperature:** The working fluid coming out from the combustion chamber will be of high temperature, hence high temperature is obtained at the inlet. Further as it moves along the blade, temperature is reduced as shown in figure 6.
- **Velocity:** The velocity considered for the small scale axial flow turbine is 350 ms^-1. As seen in the figure 7, velocity increases as it moves from the stator to rotor. Slight flow separation can be seen at the trailing edge of the rotor.

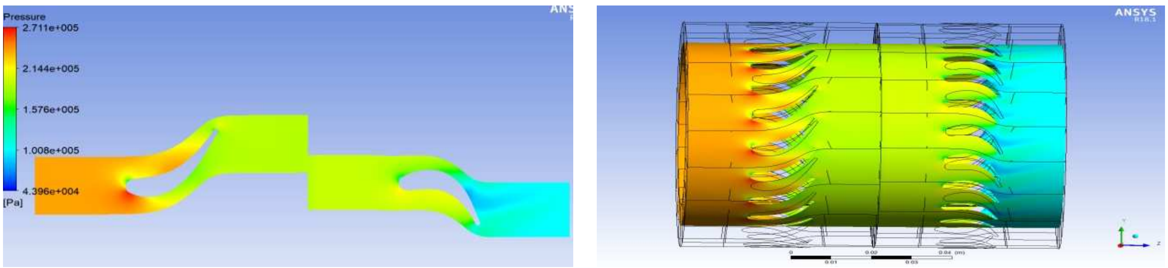

Figure 5: 2D and 3D View of Pressure Distribution along the Axial Flow Turbine

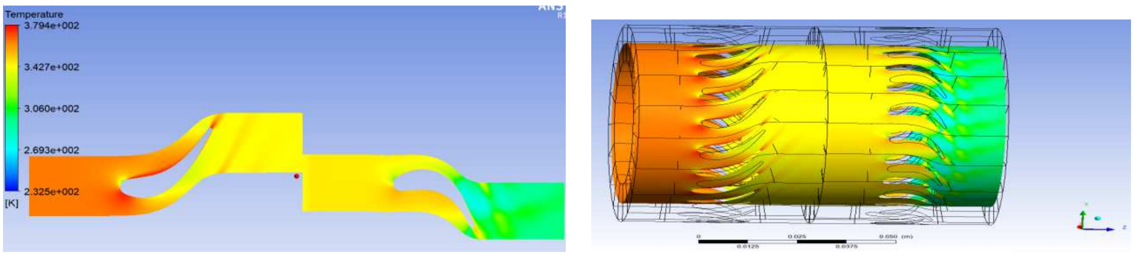

Figure 6: 2D and 3D View of Temperature Distribution along the Axial Flow Turbine

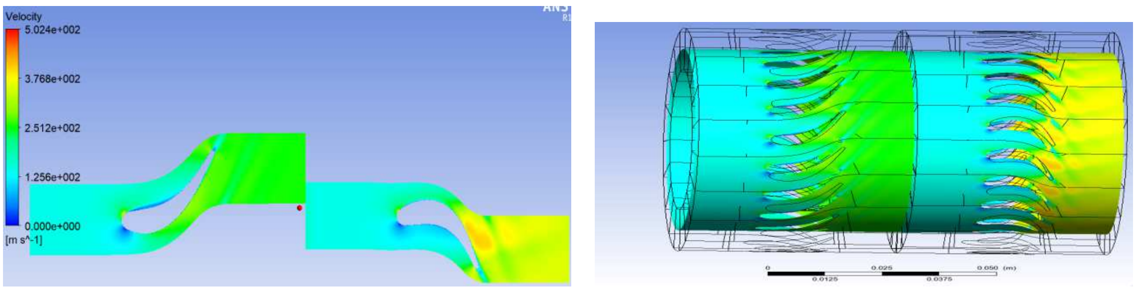

Figure 7: 2D and 3D View of Velocity Distribution Along the Axial Flow Turbine

CONCLUSIONS

- With the given data, the axial flow turbine blade profile has been modelled for the rotor blade and stator blade analytically.
- From the figure 5,6 and 7, it was observed that the flow separation at the rotor blade was slightly reduced, when examined the baseline analysis. The flow separation observed at the rotor blade was eventually high when compared with the stator blade.
- Comparing the numerical analysis with the theoretical calculation, percentage error of 1.69% was obtained and lies in the agreement within the acceptable range of theoretical calculation.
- Numerical analysis carried out in ANSYS was cost effective as many number of modification was done in the same system effortlessly, when compared to a real time system.
- Lowest pressure value and highest velocity was observed at the suction side of the turbine blade.
- The load distribution through the rotor passage was improved through the present model when compared with the base reference, thereby enhancing the flow along the blade surface.

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